Evaluating Software Architecture for Sustainability

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DiSC DIGITAL SUSTAINABILITY CENTER

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The 128 Ads - Problem

Design decisions

- Clean Architecture for Android App
- Use of a proprietary library (video player)

But,

- Crashes in Production
- Logs tell no story …
- Battery drain

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The 128 Ads - Discovery

Resource Leak

“Zombie Listener”

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The 128 Ads - Result

- High energy use – environmental
- Revenue lost – economic
- User trust lost – social issue
- Developer time lost – social/economic

? An over optimized application – technical

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What is sustainability?

“balance of quality concerns for long term benefit”

Patricia Lago, Sedef Akinli Koçak, Ivica Crnkovic, and Birgit Penzenstadler. Framing Sustainability as a Property of Software Quality. Comm. ACM, 58(10), 2015.


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‘quality concerns’

- Modifiability
- Energy Efficiency
- Operational Cost
- Security


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Sustainability as a ‘quality concern’

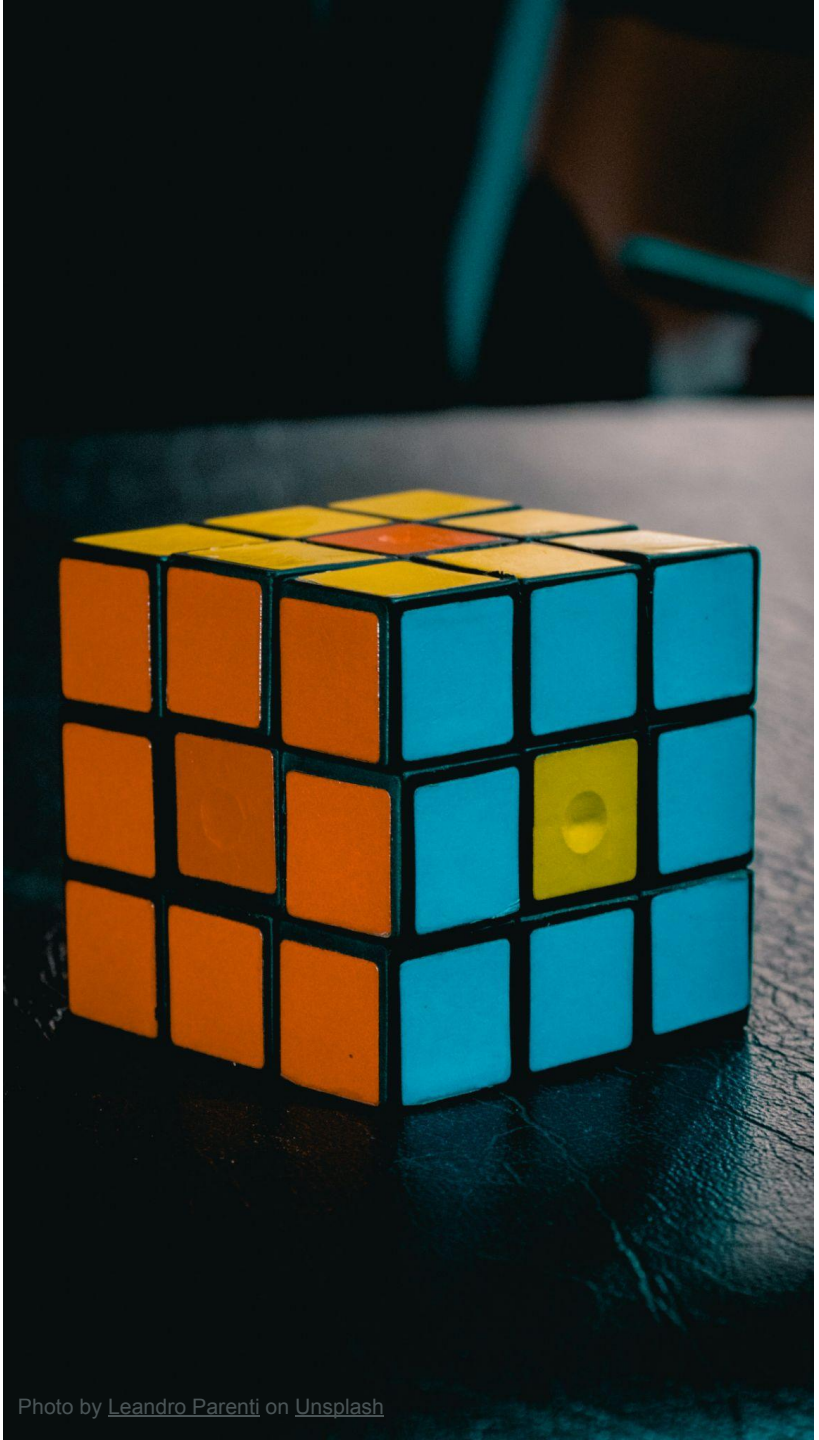
- Modifiability
- Energy Efficiency
- Operational Cost
- Security

Patricia Lago, Sedef Akinli Koçak, Ivica Crnkovic, and Birgit Penzenstadler. Framing Sustainability as a Property of Software Quality. Comm. ACM, 58(10), 2015.

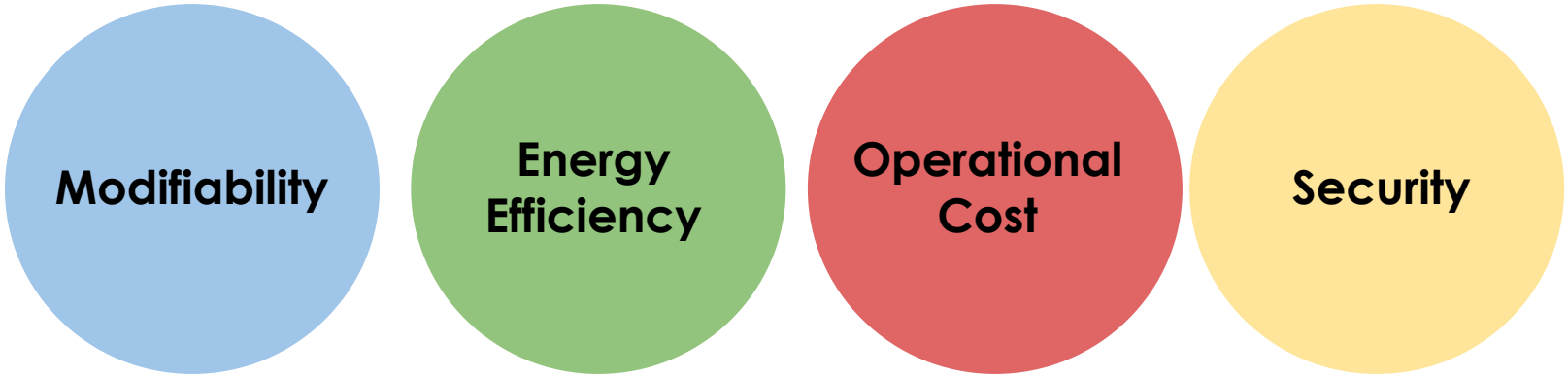
Photo by Adi Rahmadhasuma on Unsplash

Goal

To achieve a balance between the different quality levels while achieving long term benefits.



I. Multidimensional Nature



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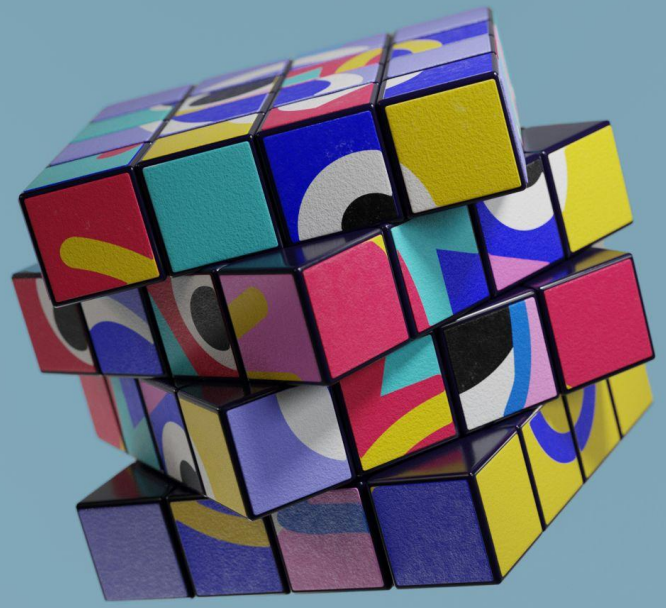
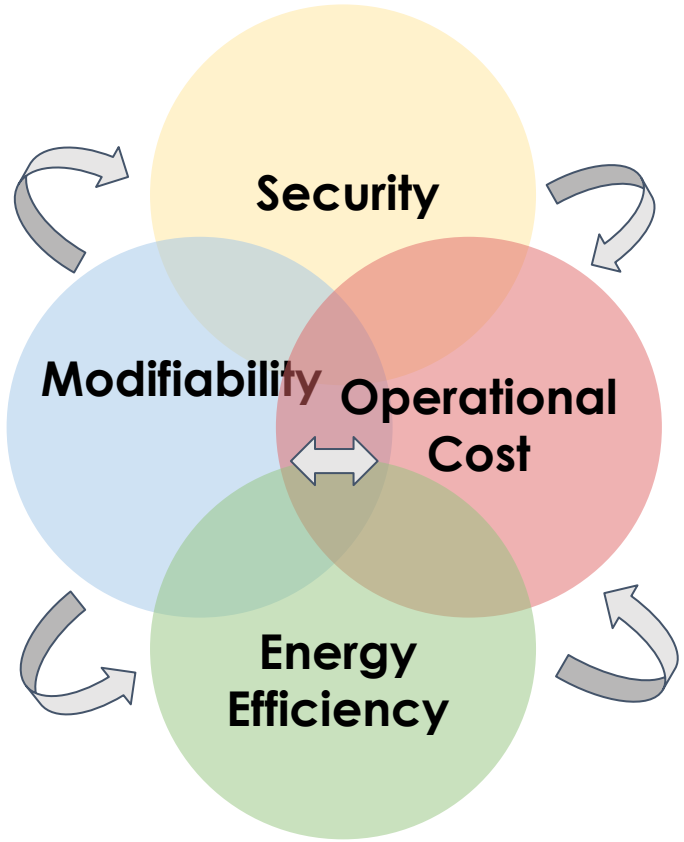
II. Cross-cutting Nature





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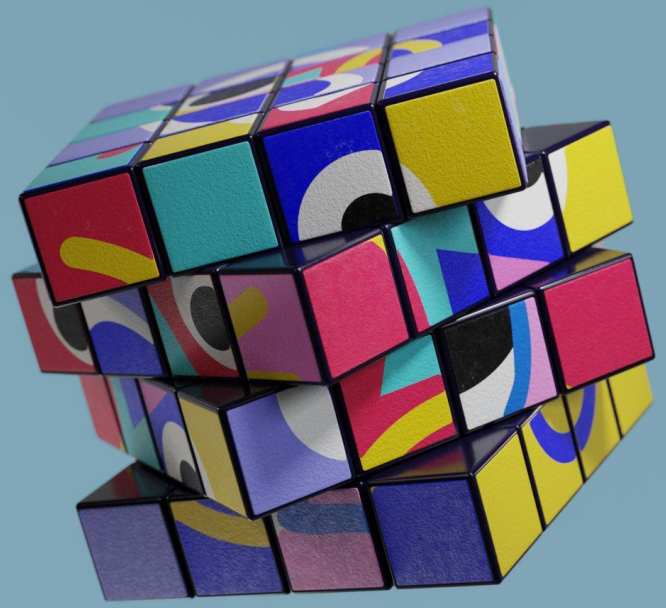
III. Over time Impacts



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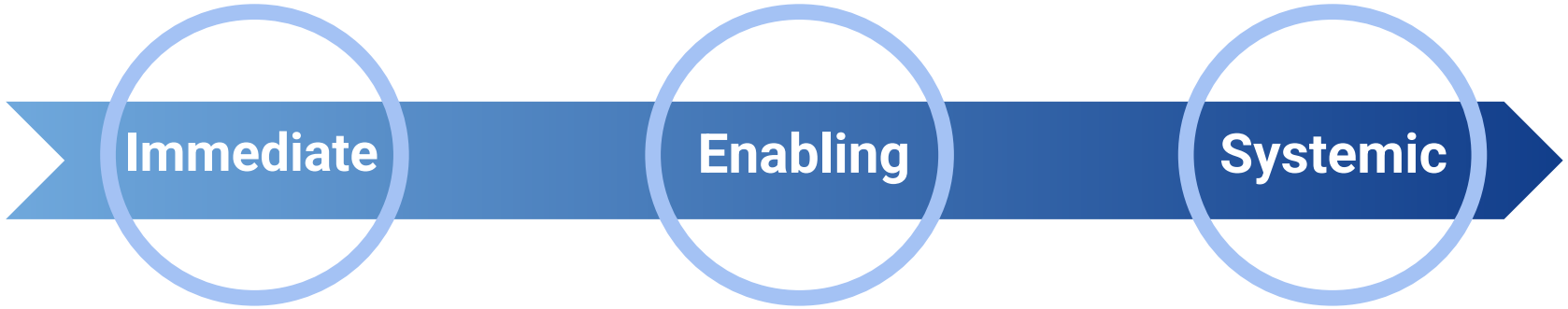

Photo by Adi Rahmadhasuma on Unsplash

Goal

To achieve a balance with long term benefits.

-
-
-
-

Holistic evaluation of software architecture

Patricia Lago, Sedef Akinli Koçak, Ivica Crnkovic, and Birgit Penzenstadler. Framing Sustainability as a Property of Software Quality. Comm. ACM, 58(10), 2015.

The Evaluation Method

Techniques
Examples
Reflections

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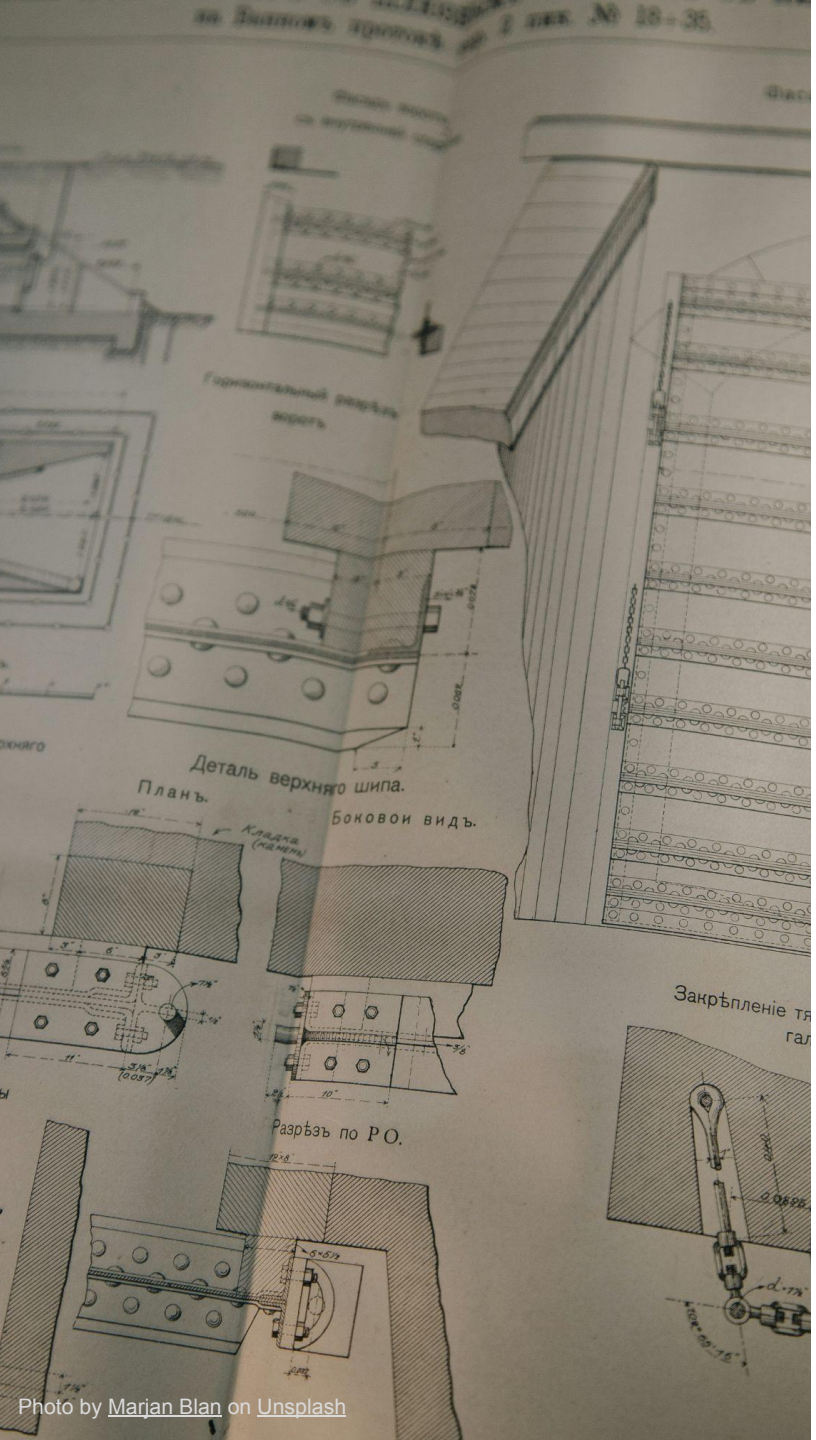

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Case Studies

- Learning Management System for education at a Dutch university
- Multi-model system for energy modeling for Dutch public sector
- Multi-tenant SAAS application for real estate sector in the Netherlands

Photo by Brandi Redd on Unsplash

Evaluation Goal

Answer: Sustainability

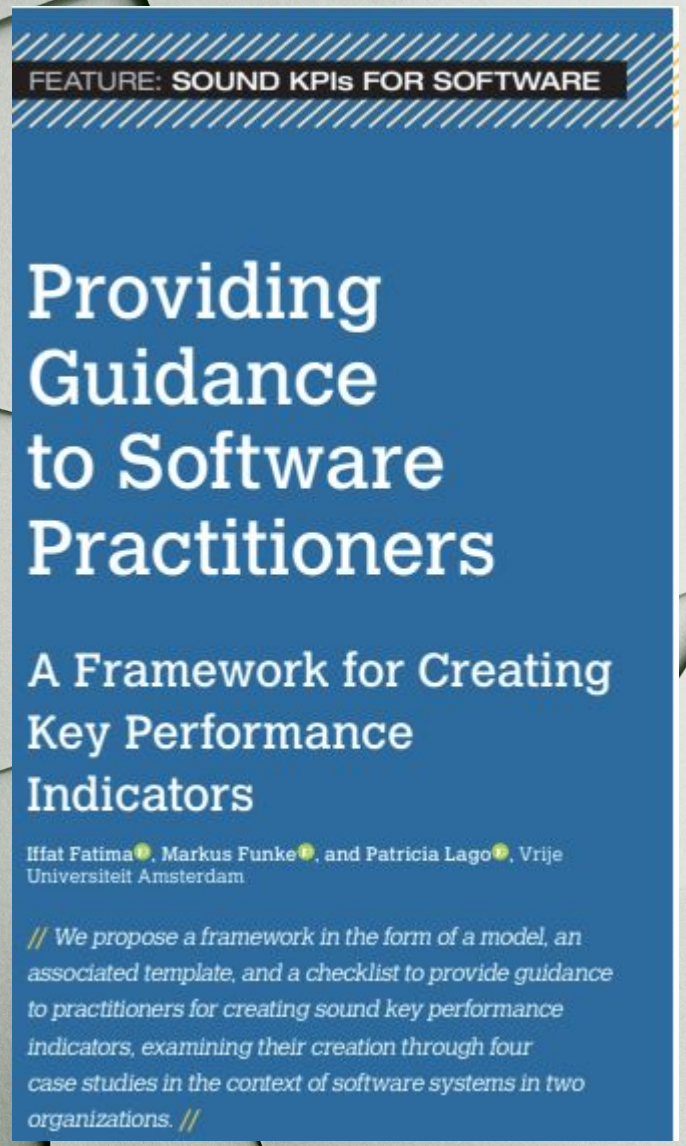
But what does that really mean for

YOUR organization?

Key Performance Indicators

- Model
- Template
- Checklist

I. Fatima, M. Funke and P. Lago, "Providing Guidance to Software Practitioners: A Framework for Creating Key Performance Indicators," in *IEEE Software*, vol. 42, no. 4, pp. 68-78, July-Aug. 2025, doi: 10.1109/MS.2024.3456446.



KPI Example

Availability

=

(MTBF / (MTBF + MTTR)) x 100

Availability

=

(No. of successful transactions / No. of total transactions) x 100

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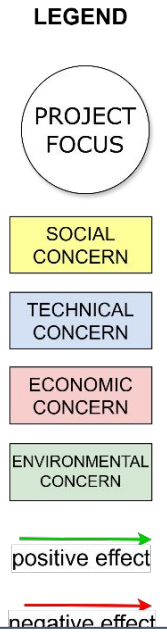
Exploring the Problem Space

Elements of the SAF Toolkit

1. Decision Maps



Look out for the workshop tomorrow

09:00 AM - 12:00 PM

Workshop // Architecting for Sustainability with the SAF Toolkit (ENG)

By **Markus Funke** / Ph.D. Candidate in Software Sustainability at Vrije Universiteit

Lago, P., Condori Fernandez, N., Fatima, I. et al. The sustainability assessment framework toolkit: a decade of modeling experience. Softw Syst Model (2024). https://doi.org/10.1007/s10270-024-01230-9

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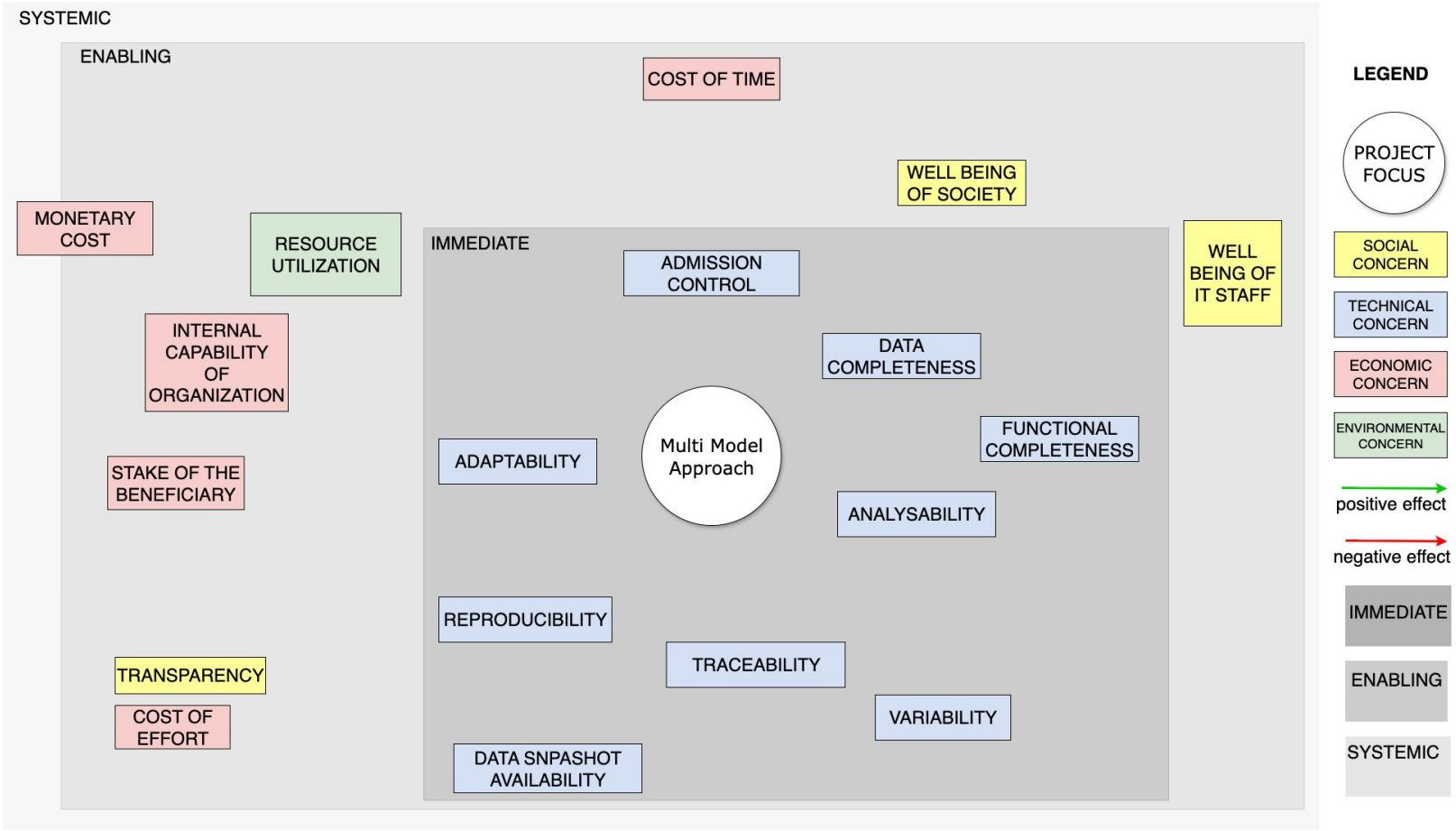
Exploring the Problem Space



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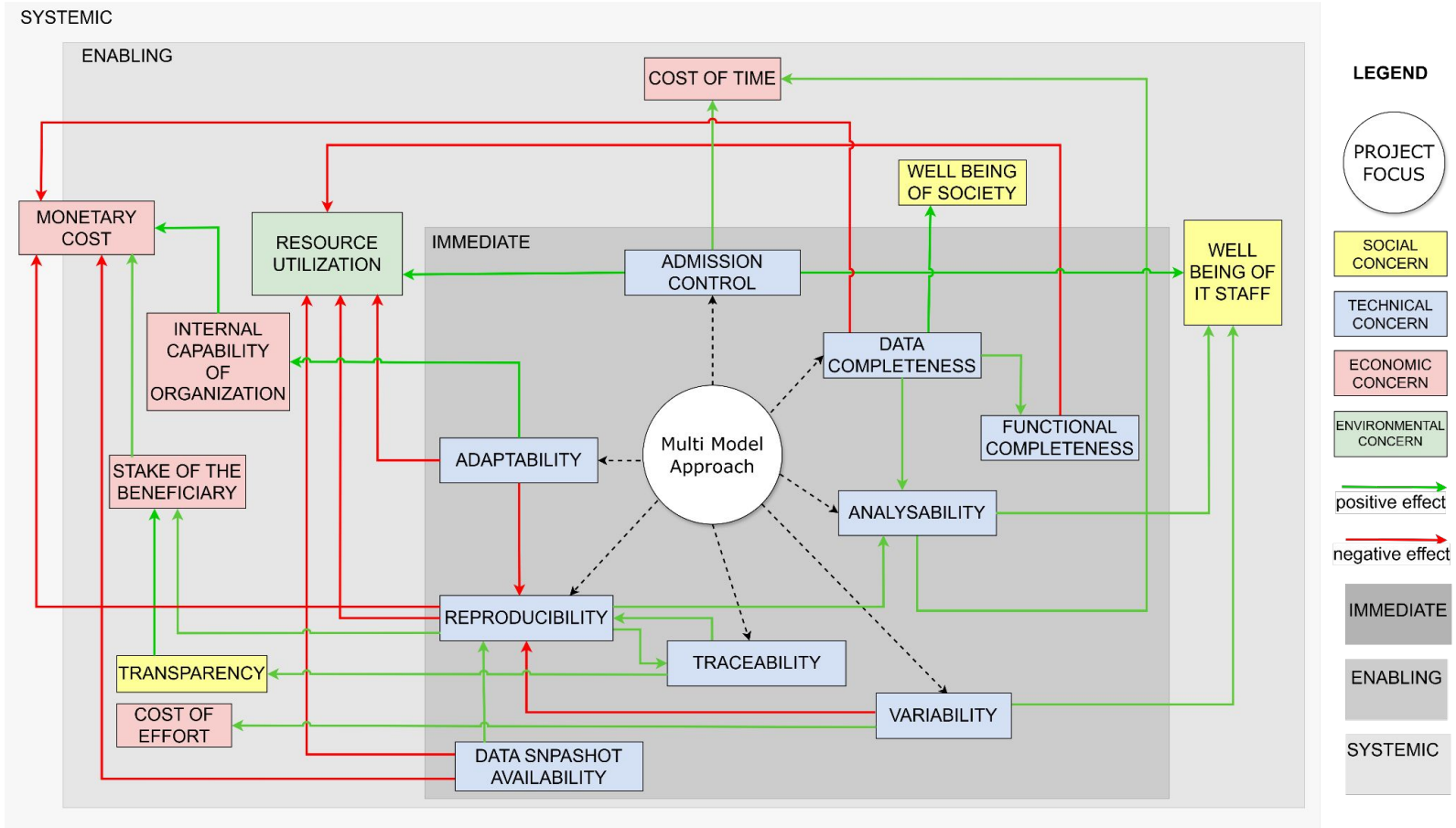
Trade-off information



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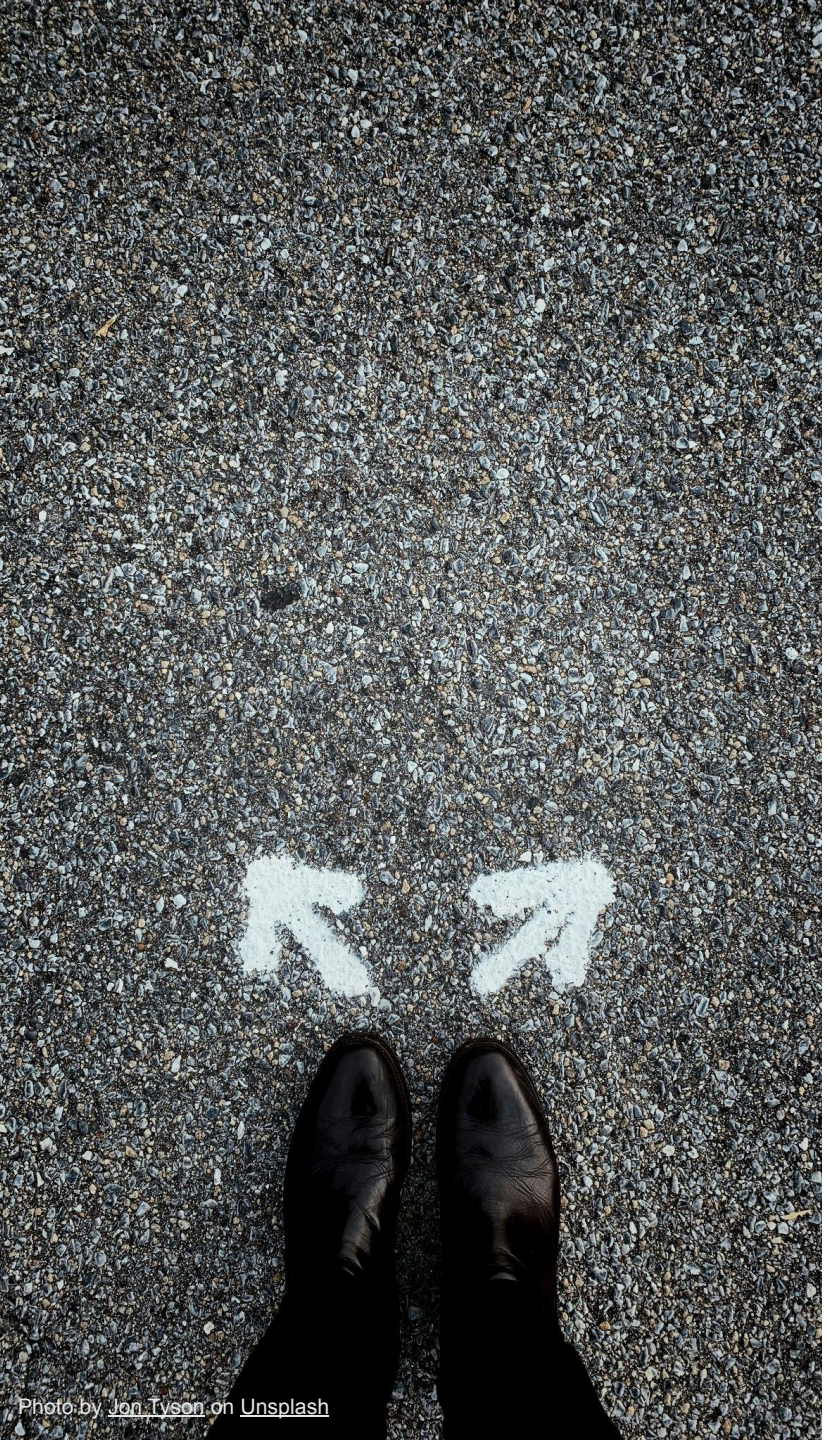

Example: DMatrix Multi Model

Quality Attributes	Economic	Cost of Time	Cost of Effort	Monetary Cost	Increasing Internal Capability	Stake of beneficiary
Technical	**Priorities**	0.10	0.10	0.10	0.10	0.10
Adaptability	1.00				1	
Variability	1.00		1			
Concurrency	0.78	1				
Data Completeness	0.78			-1		
Analysability	0.33	1				
Reproducibility	0.33			-1		1
Data Snapshot availability	0.10			-1		

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Photo by Oscar Ivan Esquivel Arteaga on Unsplash

Prioritization of QAs

1. What is the **importance** of quality concern towards functioning of the system?
2. What is the **risk** if a quality concern is not satisfied?

`Priority = f (importance, risk)`

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Trade-offs
between quality concerns

(a) SERVERLESS

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	-
Latency *p=3*	o	o
Portability *p=2*	o	-

(b) CONTAINERIZATION

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	+
Latency *p=3*	-	o
Portability *p=2*	o	+

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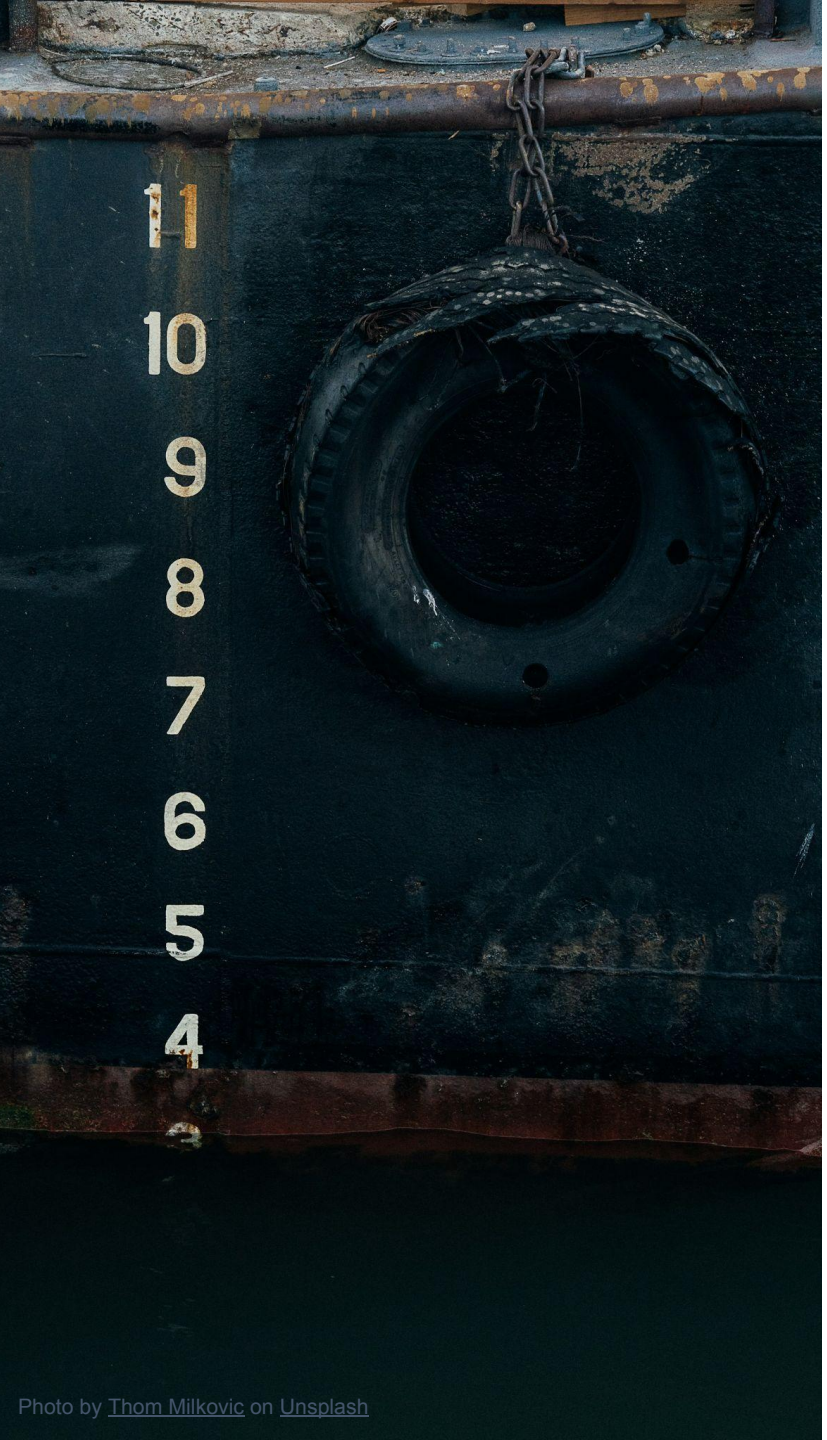

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Sustainability Impact Score

$$\mathrm{SIS}_{dim1,dim2} = \sum_{\substack{i=1 \\ j=1}}^{n,m} (\mathrm{Priority}_{dim1\_i} + \mathrm{Priority}_{dim2\_j}) \times \mathrm{Impact}_{ij}$$

where n=total QAs per dimension dim1, m=total QAs per dimension dim2

dim ∈ {Ec, En, S, T}, impact = {+1, -1, 0}

A higher score indicates a relatively higher positive impact between dimensions

Sustainability Impact Score (SIS) enables observation of inter-dimension trade-offs.

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Trade-offs
between quality concerns

(a) SERVERLESS

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	-
Latency *p=3*	o	o
Portability *p=2*	o	-

Sustainability Impact Score (SIS) = 0

(b) CONTAINERIZATION

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	+
Latency *p=3*	-	o
Portability *p=2*	o	+

Sustainability Impact Score (SIS) = 11

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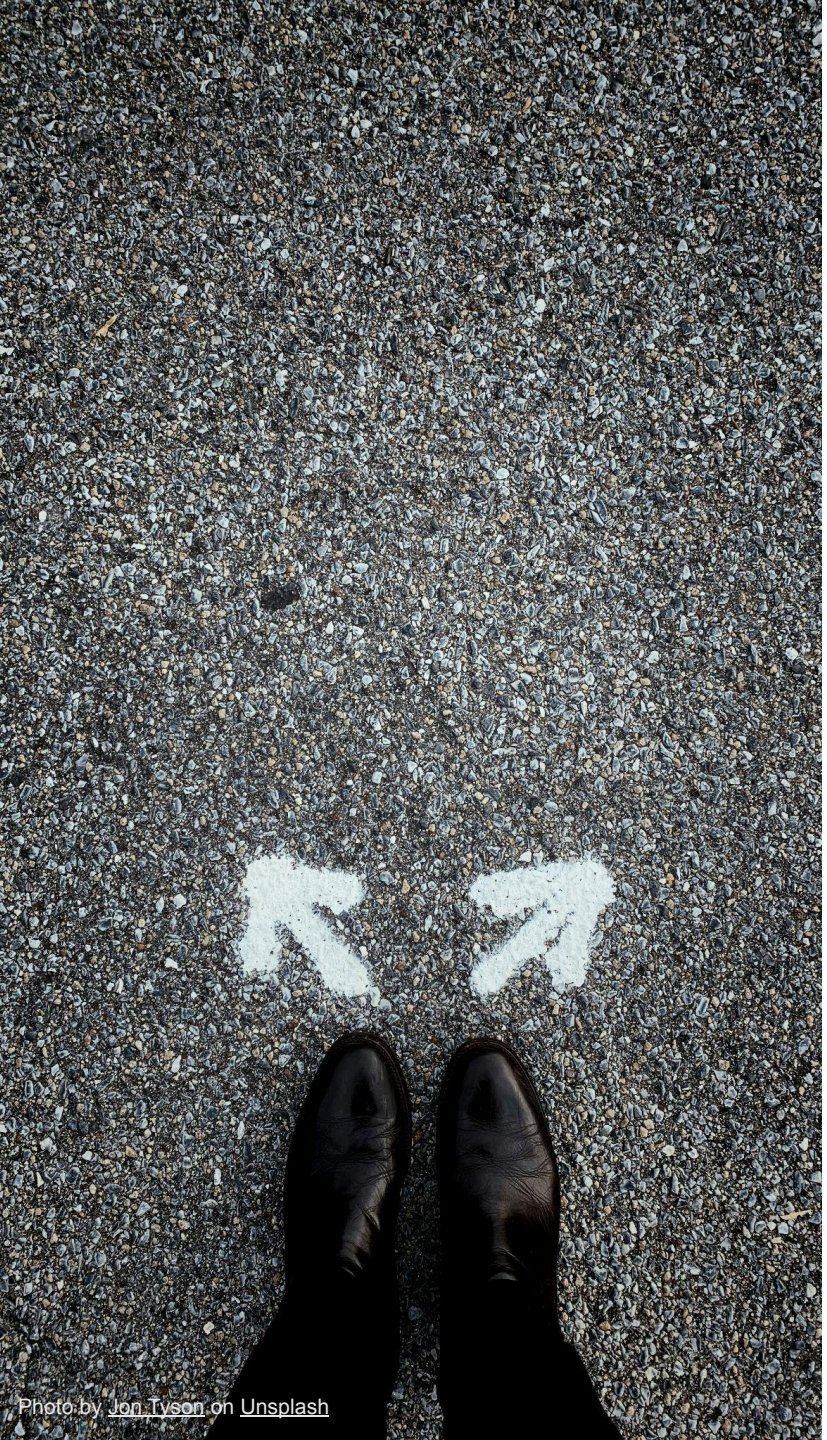


How to compare the SIS values?

- **No available standard/benchmark**
- **No upper or lower limits**

So,

We ask the stakeholders:

What is the optimal best case scenario, realistically?

Photo by Leandro Parenti on Unsplash

Optimal Score

(a) SERVERLESS

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	-
Latency *p=3*	o	o
Portability *p=2*	o	-

Sustainability Impact Score (SIS) = 0

(b) CONTAINERIZATION

Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	+
Latency *p=3*	-	o
Portability *p=2*	o	+

Sustainability Impact Score (SIS) = 11

(c) Theoretical Optimal

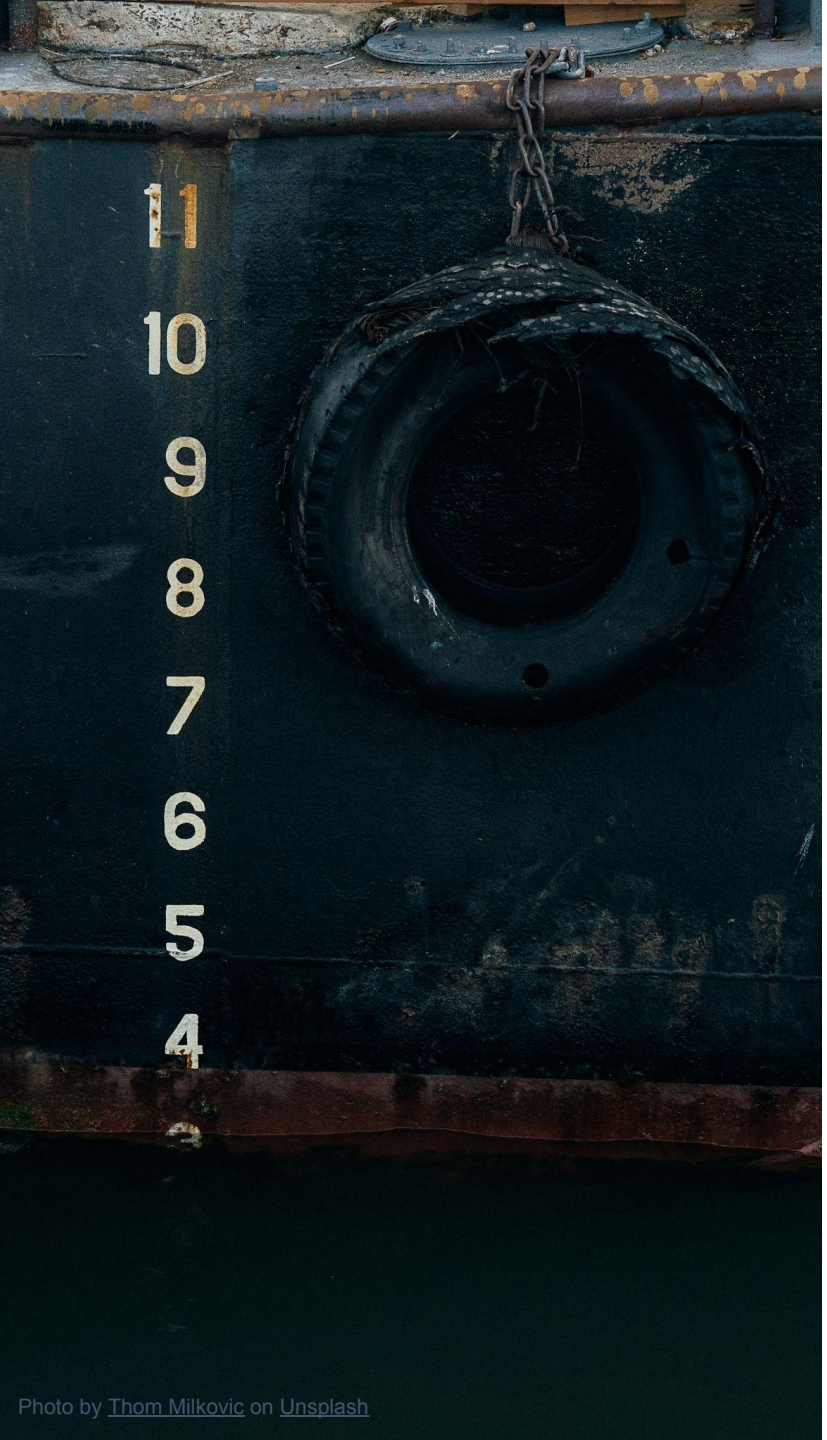
Economic Dimension

Technical Dimension

QUALITY ATTRIBUTES	Cost Efficiency *p=4*	Vendor Independence *p=1*
Scalability *p=5*	+	o
Latency *p=3*	+	o
Portability *p=2*	+	+

Sustainability Impact Score (SIS) = 31

I. Fatima, P. Lago, V. Andrikopoulos and B. van der Waaij, "Using Sustainability Impact Scores for Software Architecture Evaluation," *2025 IEEE 22nd International Conference on Software Architecture Companion (ICSA-C)*, Odense, Denmark, 2025, pp. 60-68, doi: 10.1109/ICSA-C65153.2025.00017.



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Sustainability Impact Score

Architectural Approach	Sustainability Impact Score (SIS)			
	Technical – Economic	Technical – Environmental	Technical – Social	Social – Economic
Single Model Approach	0.00	**28.41**	0.00	0.00
Multi Model Approach	**76.51**	0.00	**100.00**	**100.00**
Theoretical Optimal	100.00	100.00	100.00	100.00

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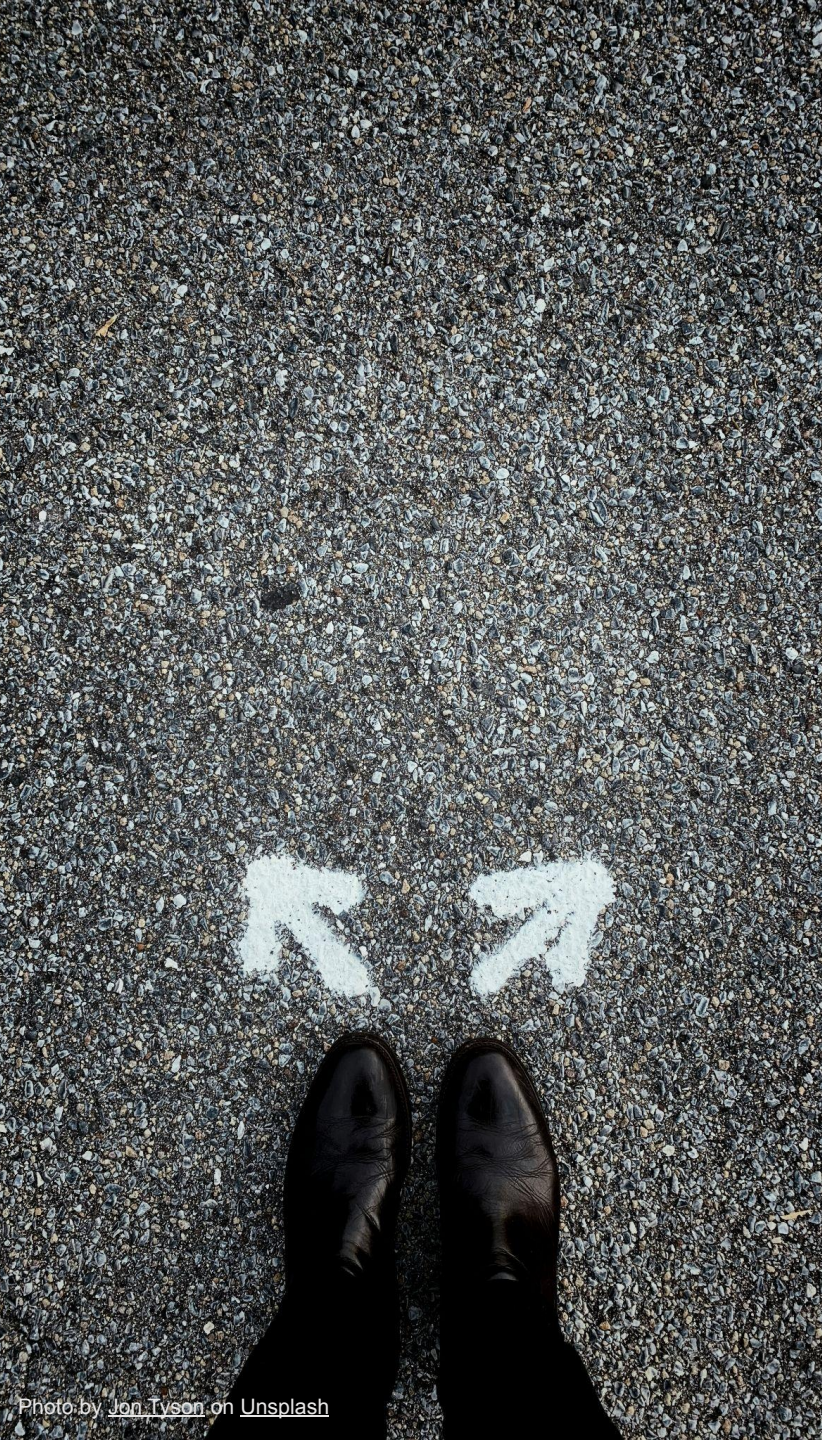


How does SIS help in decision making?

Scenario: Learning Management System used by 2 universities

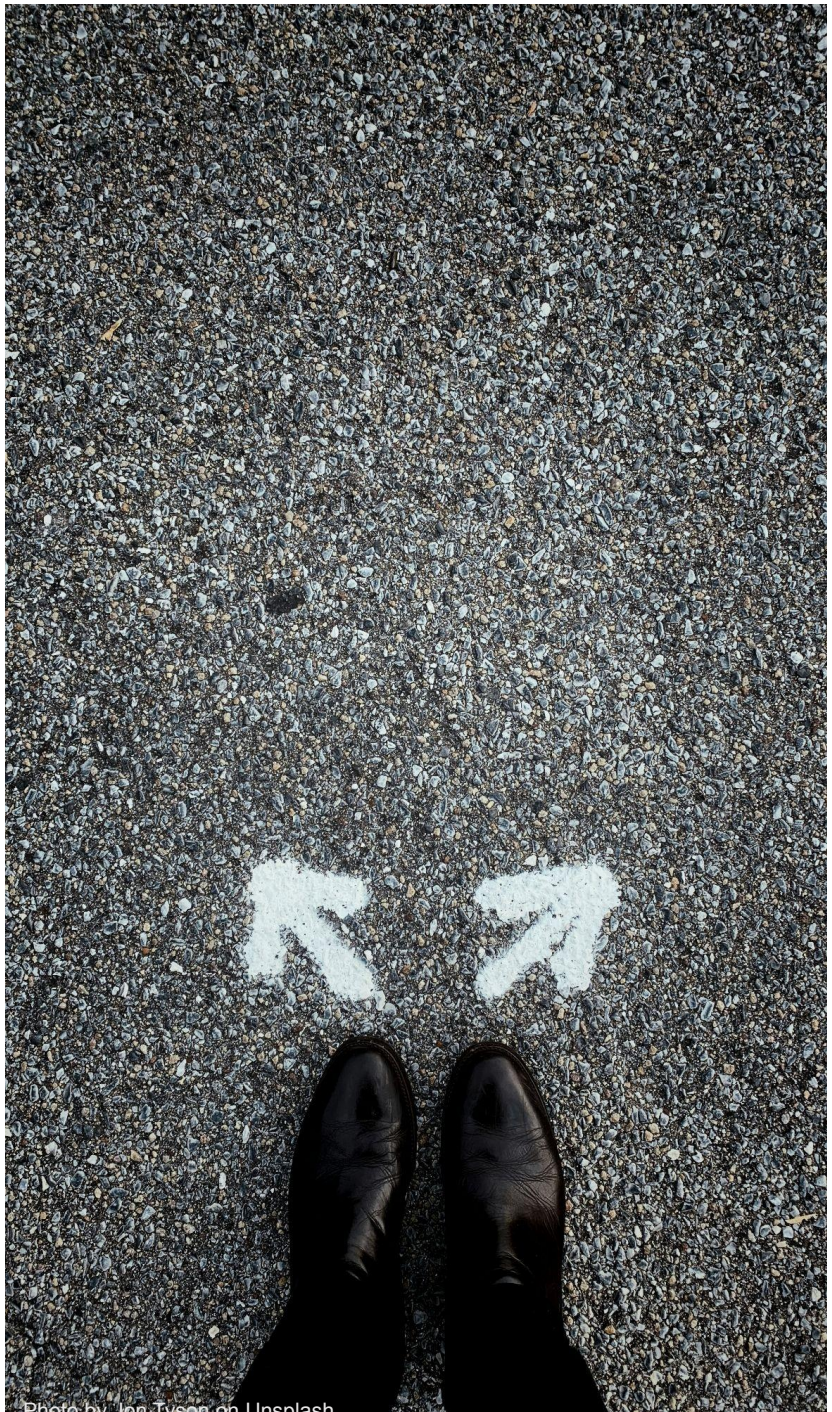
Design Option 1: Separate production instances

Design Option 2: Shared production instance

SIS	Design Option 1 (2 prod. instances)	Design Option 2 (1 prod. instances)
Technical, Economic	**89**	67
Technical, Environmental	2	**13**
Technical, Social	87	87

Decision Currently In place

I. Fatima and P. Lago, 'Software Architecture Assessment for Sustainability: A Case Study', in *Software Architecture: 18th European Conference, ECSA 2024, Luxembourg City, Luxembourg, September 3–6, 2024, Proceedings*, Luxembourg City, Luxembourg, 2024, pp. 233–249.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Trade-offs
between dimensions

SIS	Design Option 1 (2 prod. instances)	Design Option 2 (1 prod. instances)
Technical, Economic	**89**	67
Technical, Environmental	2	**13**
Technical, Social	87	87

Decision Currently In place

Design Option 1

➔ **Supports Economic sustainability**

- ◆ in terms of saving maintenance and portability costs

➔ **Hinders Environmental Sustainability**

- ◆ by using more resources

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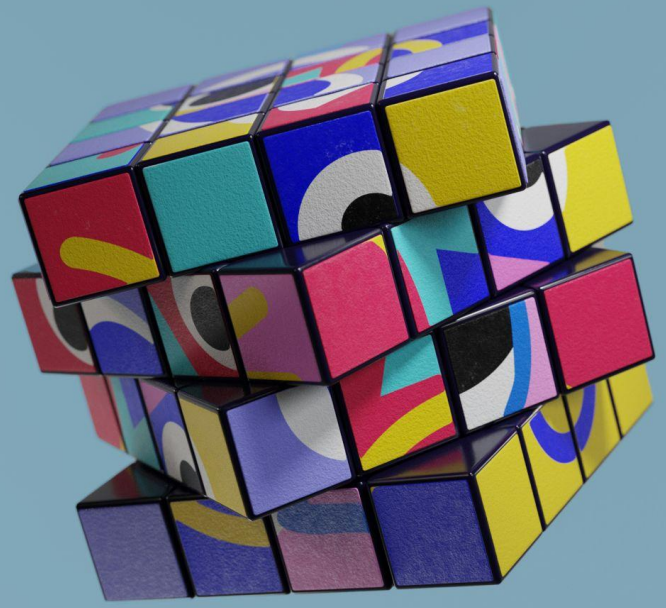
Questions to ask while designing your next architecture

1. How do we define quality X for OUR system?
2. How important is quality X for this feature?
3. What is the impact NOW and in X YEARS?
    a. On the product, society, environment and ofcouse, the economy.
4. What is the value of impact? Is the trade-off worth compromising on the long term goal?



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Key Takeaways

1. Navigating the human element
2. Setting limits to the scope of impacts
3. Avoiding getting lost in numbers
4. Always pivot to the goal and context
5. Rethink priorities
6. We need benchmarking!

Thank you.

i.fatima@vu.nl

This artifact is part of the project **SustainableCloud** (OCENW.M20.243) of the research programme Open Competition which is (partly) financed by the **Dutch Research Council (NWO)**.

Evaluate Proactively

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SIS Helps. What more can we do?

Photo by Rupinder Singh on Unsplas

Knowledge and skill transfer through collaboration

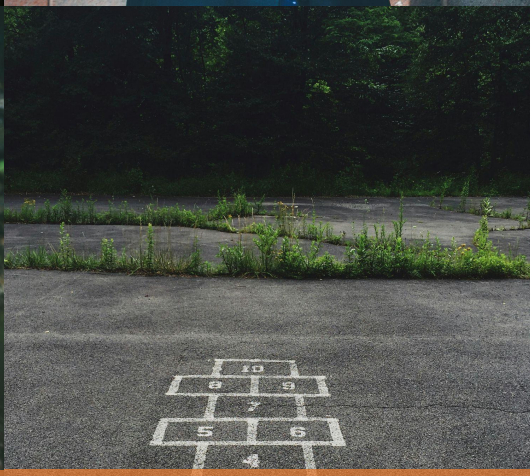
Photo by Siora Photography on Unsplash

Prioritize with Care

Photo by Mesh on Unsplash

Identify hidden impacts Hint: Decision Maps

Photo by Harjinder Cheema on Unsplash



Reuse! The playground is yours!

Photo by Jon Tyson on Unsplash

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